

Self-induced radiation of 4.3 GeV electron beam in crystalline medium

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Abstract

Investigations of interactions of a relativistic electron beam with single crystals have shown that yields of gamma rays, their energies and outgoing angles grow non-linearly with the beam intensity especially at small incidence angles of electrons relative to crystalline planes and axes. It is observed peculiar role of a crystal boundary in these phenomena. One can consider coherent properties of physical vacuum, manifested near the crystal boundary are responsible for correlation processes in electromagnetic interactions of the relativistic electrons.

1 Introduction

As known non-equilibrium processes perform constructive role in physics, chemistry and biology. They define origin coherent structures and self-organization process [1]. The stronger non-equilibrium the deeper inter -connection of different phenomena and essences. That is way any more energy, laser fields, currents and intensity of irradiation is used. Lee [2], for example, proposed to investigate the coherent properties of physical vacuum exciting it's by colliding ultra-high energy heavy nuclei.

The same concerns electromagnetic vacuum. Quantum electrodynamics is studied well on short distances. Electrodynamics of intense fields is needed in experimental investigations. As will be shown below growth of intensity of the electron beam result in manifesting the coherent properties of vacuum due to which correlation of excited atoms comes, responsible for modifications of electromagnetic processes in crystalline medium.

2 Experimental results

Experiments carried out by means of 4.3 GeV electrons moving in single crystals of diamond and others since 1976 on the internal electron beam of Yerevan Synchrotron. The advantage of the last is multiple passage of electrons through thin target, that equivalently acting more intense current of accelerator. Evidence in paper [3] indicates that crystalline medium excited by intense electron beam influences on electromagnetic cross-sections of passing relativistic electrons. Data presented in paper [3] show anomalous growth of emission angles of gamma rays. New data, involved in this paper, concern effects of crystal edges in conditions when size of crystal is commensurable with beam one or electron beam pass through crystal near its edge. These conditions, which take place in all cited papers, apparently, are responsible for non-linear processes, mentioned in the beginning of this article and other [4, 5]. In this paper new experimental data are presented together with some published data for confident evidence of afro-cited statements. Preliminary investigations of interactions of electron bunches passing near planes (110) and axes [100] have shown:

1. Arising intense radiation is low-energy one in main. This conclusion based on such a fact. Synchrotron radiation losses of electrons in accelerator are ≈ 1.5 MeV per one revolution. If energy losses in crystal are compatible with this value then electrons at defined tuning of the accelerator can dump to the vacuum chamber wall near the diamond target in main. The experimental setup is presented in [3]. Detector situated near the target really showed sharp growth of counting rate in depending on beam intensity and crystal orientation [4]. However counting rate of this detector significantly exceeds one of any gamma-quanta detectors. It is one of evidence that a part of anomalous radiation extends large angles and therefore does not pass through collimator or has very low energy.

2. Anomalous radiation arises when intensity of the electron beam passing through single crystal exceeds some threshold, i.e. radiation in a crystal increases non-linearly. Integrated yield of gamma rays grows by power law with the electron beam intensity up to I^4 (evidence of a phase transition), where I is electron current. In doing so it is observed also strong almost 100% dumping of accelerated electrons when their bunches pass under the small angles relative to planes (110) of the crystal and just only 4% at the disoriented crystal.

3. Production of intense gamma rays is observed with the diamond crystal of 100 and 470 μm . Yield of low-energy gamma quanta from the crystal (470 μm) approximately equal to one with thickness 100 μm . It means production of soft radiation occurs due to interaction in front part of the crystal. That is a consequence of large interaction cross-section of electron and subsequent screening of other atoms [4].

4. Degree of gamma beam polarization is high, when electrons travel through the crystal in parallel to planes (110). This conclusion was made on the base of measured azimuth asymmetry 0.81 [3]. This asymmetry was measured at scattering of low energy radiation by amorphous target (polystyrene of 1.5 cm thick) under the angle of 20 mrad. Azimuth asymmetry of linear Compton- scattering of hard gamma quanta at small angles does not exist. One can think observed azimuth asymmetry is connected with property of boundary of excited polystyrene medium and with high coherence of gamma beam.

5. As noticed in [3] quantities of total radiation passing through two different collimators non-proportional to the ratio of their aperture areas. Possible explanation is given below. New similar results were obtained in conditions when electron beam passed through edge of diamond target. Produced gamma rays traveled through collimator with subsequent scattering of photons under the angle of 3.4° relative to the direction of gamma beam and are detected by means of simple counter with thin scintillator of ZsJ. The energy of accelerated electrons was 2.9 GeV and scattering target was polystyrene of 5mm thickness, situated on the distance of 28 m from diamond-radiator. A strong magnetic field swept all produced charged particles. It is studied dependence of detector counting rates on crystal orientation firstly when radiation from diamond passes through collimator aperture $6.7 \times 6.7 \text{ mm}^2$ and then $3.3 \times 3.3 \text{ mm}^2$. Measured counting rates were normalized to the quantameter data. The normalized counting rates sharply fell down at orientation of crystal plane (110) near 0° in case of collimator aperture $3.3 \times 3.3 \text{ mm}^2$ (table 1).

Orientation, mrad	Aperture 6.7×6.7	Aperture 3.3×3.3
0.0	1665000	587000
0.085	1660000	597000
0.42	1430000	590000
0.85	1580000	627000

Table 1: Normalized counting rates of ZsJ detector versus the collimator aperture and crystal orientation.

So cutting off the normalized yields of radiation almost 3 times is observed. One can think that this phenomenon arises because of a part of intense radiation is produced on the edge of radiator and has more wide angular distribution and different spectrum. In item 6 last argument (edge) for that conclusion is demonstrated more brightly.

6. In this measurements movable diamond radiator with transversal size of 2 mm could displace together with electron beam in transversal direction relative to aperture of collimator $3.3 \times 3.3 \text{ mm}^2$, which was placed on the distance of 9.4 m from radiator. So collimator took gamma beam only from defined part of diamond. Monitoring of total energy of radiation was carried out by means of Wilson quantameter. Table 2 present the counting rates of the detector, situated under angle 6° relative to gamma beam direction and the same detector under angle 19° versus coordinate of diamond displacement r . Crystal orientation relative

to planes (110) was 0° . It is seen increase of the detector counting rate when collimator "sees" only an edge of the crystal. Why the edge?

r, mm	Detector 6°	Detector 19°
0	16000	995
0.5	25100	1300
2	38400	1920

Table 2: Normalized counting rates of detectors depending on the cristal displacement relative to the collimator aperture.

Breaking spatial symmetry near edges of crystal [6] is simple explanation. In this topology vacuum is polarized. Coherent properties of vacuum result in ordering atomic excitations due to primary polarization, i.e. synchronization of atomic fields, which create a strong field. Relativistic electrons moving in that field produce intense synchrotron-like radiation. Apparently, broadened angular distributions of photons with energies 300-800 MeV in [7] demonstrate this statement. So symmetry breaking on the boundary is responsible for arising strong field on the edges of excited crystal. There is experimental evidence, that coherent bremsstrahlung and channeling one in the same conditions are decreased. Cause for such a behavior is absence of particle oscillations on its way because of superposition of mentioned low-frequency strong field. Electron will be deflected in some direction on the more large distance already. Respectively angles of gamma-emission grow also.

7. There are measurements, which show that even a very hard part of bremsstrahlung spectrum grows with electron beam intensity at any orientation of the crystal. That growth more two times is shown in table 3. Particles are detected in this experiment only from hadrons produced in the reaction $\gamma + \text{nucleus} \rightarrow \text{hadrons}$, as detector was placed under large angle of 19° relative to gamma beam direction. Electron beam intensity was increased in this measurement due to faster beam-dump.

Orientation, mrad	Slow beam-dump	Faster beam-dump
0.0	551	1180
0.34	703	1630
1.0	894	2110

Table 3: Normalized counting rates of detector versus electron beam intensity and crystal orientation.

These measurements showed strengthening of the atomic fields at small impact parameter and prove once again existence of mentioned strong field because of atomic correlation.

3 Conclusion

So obtained data in item 1-7 show that radiation cross-sections of relativistic electrons, the energy of emitted photons and outgoing angles of hard radiation grow by virtue of medium coherence when intensity of the electron beam is increased. Process of ordering of atomic

interaction result in both different kinds of photon emission of relativistic electrons, which are superposed against each other in radiation spectrum:

1. Cherenkov, quasi-Cherenkov, transition radiation. They have polarization nature, when high-energy electron interacts with atoms.

2.Bremsstrahlung, coherent bremsstrahlung, channeling and synchrotron-like radiation , when electron does with atomic Coulomb-fields of oriented crystal.

When crystal is excited all these processes are modified. Coherent bremsstrahlung and channeling radiation are partially suppressed, however transition and synchrotron-like radiation are strengthened.

Different applications are possible for described phenomena It is possible creation (in dependence on energy of electrons, their beam intensity and kind of accelerators):

1.Intense source of linear polarized gamma quanta, in particular, gamma-laser.

2.Method for measure the degree of gamma beam linear polarization.

3.Intense source of positrons.

4.Quark-gluon plasma, if to collide intense gamma beams, produced on crystals from counter-electron beams of future linear colliders.

In measurements, marked by item 5 Garibyan V. and Vartanov Yu. participated also. The work is supported by contract 116 of RA government and partially by CRDF AP2-2305-YE-02.

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